FATIGUE CRACK GROWTH RATES IN EQUINE CORTICAL BONE

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INTRODUCTION
Stress fractures are common in athletes, military recruits, and Thoroughbred racehorses, and may occur as hip fractures in the elderly. All of these injuries, to some extent, depend upon the propagation of fatigue cracks. Therefore, it is important to characterize the rates at which fatigue cracks grow and how microstructural differences found in cortical bone influence the crack growth rate. Mechanical and fatigue properties of equine third metacarpal (cannon) bone have been shown to vary with cortical region. Bend specimens taken from the lateral region were stronger and stiffer than those taken from the dorsal region under monotonic loading. However, dorsal specimens had a longer fatigue life (Gibson, et al., 1995). These results suggested that crack growth rates in different cortical regions might also differ.

For most engineering materials, a log-log plot of the rate of change of crack length (a) with number of cycles (N) versus the alternating stress intensity factor (∆K) exhibits three distinct regions. At low ∆K, the crack growth rate data (da/dN) asymptotically decrease toward a threshold stress intensity factor. High ∆K values approach the fracture toughness of the material and result in fast fracture. This is manifest as an asymptotically increasing da/dN. Between these regions lies the Paris regime, which is commonly described by an equation of the form: \( \frac{da}{dN} = C(\Delta K)^m \), where C is a constant and m is the Paris law exponent. Typically, the Paris law exponent has a value of 2 to 4 for metals and alloys, and 7 to 20 for ceramics (Suresh, 1991). To our knowledge, this type of curve has not been previously published for cortical bone. We tested the hypothesis that crack growth rate, and thus the Paris law exponent, differs within the lateral and dorsal cortices of equine cannon bone, tested in cyclic, Mode I loading.

METHODS
Six pairs of equine cannon bones were obtained fresh from Thoroughbred racehorses following necropsy. A bone saw was used to rough-cut two specimens from the mid-diaphysis of each bone, one from the lateral and one from the dorsal cortex. A mill was used to machine each rough-cut piece into a compact type (C(T)) specimen (Fig.1), measuring 25.4mm x 24.4mm x 5.0mm. The specimens were oriented such that the longitudinal axis of the bone was parallel to the loading direction. Side grooves were cut to a depth of 1 mm into each C(T) specimen (Norman, et al., 1992). The purpose of these grooves was to try to prevent the natural tendency of the crack to run longitudinally, parallel to the osteons.

The specimens were randomly assigned to a test matrix which determined the starting ∆K value for each test, ranging between 1.5-4.0 MPa√m. An MTS 810 servohydraulic test system was used first to precrack and then to fatigue crack the specimens in accordance with ASTM Standard E647-95. The control system was programmed to decrease ∆K with
increasing a. Specimens were loaded at a frequency of 2 Hz.

Figure 1 - Sketch of a C(T) specimen. Specimens were cyclically loaded in tension (as indicated by arrows) to propagate a transverse crack, perpendicular to the direction of loading.

During testing a drip system was used to keep the specimens wet and warm with calcium buffered normal (0.9%) saline (Gustafson, et al., 1996) containing an antimicrobial agent. The specimen temperature was maintained at 37 ± 2°C.

RESULTS
The alternating stress intensity factors and associated crack growth rates were plotted on a log-log plot for transverse crack propagation in dorsal specimens (Fig. 2). From this figure, assuming the threshold crack growth rate is $10^{-8}$ m/cycle, the threshold $\Delta K$ is 2.0 MPa√m and the Paris law exponent is 10.2.

We were unable to obtain a similar plot for the lateral specimens since in all cases, in spite of the side grooves, the crack deviated from the desired path and ran longitudinally, thus invalidating the test. It should be noted that these results are not due to a failure of the test method, but reflect the dramatic differences in fatigue crack propagation resistance between the two regions.

DISCUSSION
The differences in crack growth behavior between the lateral and dorsal cortices appear to be another manifestation of regional property variations due, in part, to microstructural differences between regions. We expect, based on previous studies (Martin et al., 1996 a,b), that histological evaluation of the test specimens will show that the dorsal region has greater porosity and smaller osteons than the lateral region. In vivo, the dorsal region of the equine cannon bone is loaded in tension and the lateral region is loaded in compression. It is likely that the observed variations in microstructure are due to the mechanical adaptation of these regions in response to the types of loading they experience.

Figure 2 - Fatigue crack growth data for equine cannon bone, dorsal cortex.

REFERENCES

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